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EVENT RELATED BRAIN POTENTIALS AND COGNITIVE PROCESSING: IMPLICATIONS FOR NAVY TRAINING

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This report describes the evaluation of a relatively new technology, the analysis of event related brain potentials (ERPs), as a possible means of improving Navy training. The subjects were 50 Navy recruits undergoing basic military training. Eight channels of visual, auditory, and bimodal ERP data were recorded for each subject from scalp contact electrodes. Microvolt standard deviation amplitude measures were computed. During the same test session, but not concurrently, a battery of cognitive style, aptitude, and ability paper-and-pencil tests were given to the subjects.

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The subjects were clustered into two groups, or types, based on the paper-and-pencil tests. Type 1 subjects represented a "spatial processing" group, while Type 2 represented a "verbal processing" group. (Recent research indicates that the left hemisphere processes primarily verbal, analytic and sequential information, while the right hemisphere processes spatial, integrative or simultaneous information.) ERP variates were input to discriminant analysis to differentiate the two groups. No visual or bimodal ERP variates discriminated or validated the classification matrices. Auditory ERP variates differentiated ($p < .01$) and validated ($p < .005$) the two groups. Greater amplitude asymmetry areas were found with visual stimuli for the "spatial" group and with auditory stimuli for the "verbal" group. Greater sensory interaction was found in the right hemisphere for the "spatial" group and in the left hemisphere for the "verbal" group.

FOREWORD

This research and development was conducted within Task area ZF63522001, Work Unit 522.010.03.06 (Evaluating Evoked Potentials for Adaptive Instruction) under the sponsorship of the Director of Navy Laboratories. The procedure used in this Technical Report (analyzing event related brain potentials, ERPs) represents a new and relatively untried approach to research in the personnel and training area.

Earlier research in the area of biotechnology predictors of Navy performance was funded under Independent Research and Independent Exploratory Development Work Units, and described in NPRDC reports TR 77-13, TN 77-7, TR 79-13, and TR 80-26. The research described in this report was conducted to determine whether visual, auditory or bimodal ERP measures could be used to increase the effectiveness of Navy training.

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SUMMARY

Problem

Manpower skill shortages have made it necessary for the Navy to increase the effectiveness of its training programs. As one means of achieving this goal, the Navy has implemented computer-managed instruction. These training procedures are not very adaptive to differences among trainees because they primarily use self-study materials and require the students to use self-paced procedures. Techniques are required for better assessing the information processing styles of individuals so that training can be adapted to their needs.

Objective

Brain activity measures derived from computer analyses of event related brain potentials (ERPs) have been found to be related to information processing styles. The objective of this research was to determine the feasibility of using ERPs in the development of adaptive training techniques keyed to the information processing styles of individual students.

Approach

Fifty right-handed subjects were given a battery of paper-and-pencil tests to assess their cognitive styles, aptitudes, and abilities. The subjects were Caucasian male recruits undergoing basic military training. Visual, auditory, and bimodal (visual plus auditory) ERPs were recorded during the same testing session, but not concurrently. Standard deviation microvolt (SD μV) amplitudes were computed for the waveforms at four scalp sites over each brain hemisphere. Amplitude asymmetry measures were also computed. The basic ERP data were analyzed to derive measures of sensory interaction. The ERP measures were then related to the paper-and-pencil measures.

Results

The 50 subjects were divided into two types on the basis of the cognitive style, aptitude, and ability measures. One type was considered a spatial processing group (N = 18) while the other was considered a verbal processing group (N = 32). Discriminant analysis was used to assess ERP differences between the groups. Sensory interaction measures predicted and validated group membership more effectively than any other ERP derived measure. The sensory interaction could take the form of either excitation or inhibition. The spatial group showed greater inhibition in the right hemisphere while the verbal group showed greater inhibition in the left hemisphere. The spatial group showed the greatest amplitude asymmetry in response to visual stimuli, while the verbal group showed the greatest asymmetry in response to auditory stimuli.

Conclusion

ERP technology holds promise for developing adaptive instructional strategies based upon accurate assessments of individual differences in cognitive processing.

Future Direction

Research is now underway to assess the usefulness of ERPs recorded while subjects are learning and performing electronic warfare tasks. Additional research will be conducted to determine whether training can be enhanced by emphasizing visual media when training "spatial processing" students, and by emphasizing auditory media when training "verbal processing" students.

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Manpower skill shortages have made it necessary for the Navy to increase the effectiveness of its training programs. As one means of achieving this goal, the Navy has implemented computer-managed instruction. These training procedures are not very adaptive to differences among trainees because they primarily use self-study materials and require the students to use self-paced procedures. Techniques are required to better assess the information processing styles of individuals so that training can be adapted to their needs.

Objective

Brain activity measures derived from computer analyses of event related brain potentials (ERPs) have been found to be related to information processing styles. The objective of this research was to determine the feasibility of using ERPs in the development of adaptive training techniques keyed to the information processing styles of individual students.

Background

Training methods must adapt to a wider range of enlistee capabilities today than they were required to in the past. Computer-managed instruction (CMI) has made Navy training somewhat more individualized by using self-study materials and self-pacing. Nonetheless, the Navy still needs to find better ways of matching training methods with the abilities of individual students.

One new approach to matching training strategies with student requirements is based upon the assumption that there is an interaction between aptitudes and the instructional treatment they receive--the aptitude-treatment interaction (ATI). Recent research however, has only partially supported the ATI concept (Cronbach & Snow, 1977; Federico, 1978; Snow, Federico, & Montague, 1981).

Another method of adapting instruction to student needs would be to assess each student's cognitive or information processing style and then tailor the training methods to the student. Computer-managed instruction and recent developments in the direct measurement of brain activity are rapidly making this method feasible.

Recent research has suggested that the brain may have at least two hemisphere-related ways of processing information. Spatial, integrative, and simultaneous processing has been attributed to right hemisphere (RH) activity. Verbal, analytic, and sequential information processing has been associated with left hemisphere (LH) activity in most right-handed individuals. These two modes of information processing were initially discovered by anatomical studies of war-wound, lesion, and "split-brain" subjects. More recently, these procedures have been confirmed by modern computer technology and by measures of brain electrical activity such as electroencephalographic (EEG) and event related brain potential (ERP) records. EEG and ERP records show brain activity as minute signals recorded from the scalp. The EEG shows on-going activity while the ERP shows electrical activity after the brain has been stimulated (e.g., light flashes or clicks to the ears). The ERPs, measured in millionths of a volt (microvolts), are "buried" in electrical "background noise" and require computers for acquisition and analysis.

Typically, for people performing verbal tasks, there is decreased EEG and ERP amplitude over the left hemisphere. For spatial tasks, there is generally a decrease over the right hemisphere. Such decreases in amplitude are considered indexes of increased information processing within the affected hemisphere. Some individuals employ a predominantly verbal-analytic cognitive style for learning, problem solving, and decision making; whereas others employ a predominately spatial-integrative cognitive style for such tasks (Bogen, 1969; Galin & Ornstein, 1972; Dimond & Beaumont, 1974; Callaway, 1975; Galin & Ellis, 1975; Knights & Bakker, 1976; Ornstein, 1977; Kinsbourne, 1978).

Recent research has shown that ERP measures may be able to predict on-the-job performance better than existing paper-and-pencil tests (Lewis, 1979 & 1980; Lewis & Rimland, 1980; Lewis & Froning, in press).

Current training and testing techniques make heavy but unsystematic use of both verbal-analytic processes and spatial-integrative processes. One of the implications of brain lateral asymmetry concepts for training is that students could be trained more effectively by emphasizing visual media with "spatial" students and auditory media with "verbal" students.

There is evidence in the literature for relating the right hemisphere to visual processes and the left hemisphere to auditory processes (Carmon & Bechtoldt, 1969; Friedman, Simson, Ritter, & Rapin, 1975; Shipley, 1977).

Jones (1972) has reviewed the behavioral literature dealing with sensory interaction and reading ability. Sensory modality-training technique studies have suggested relationships between language processing abilities and preference for the visual modality. Jones mentions that many of the reviewed studies do not show positive relationships between teaching a subject in his preferred sensory modality, whether visual or auditory, and enhancement of learning. Accurate assessment of the preferred modality was a problem, however. Perhaps a more direct assessment of modality preference through ERP procedures would be more accurate. Use of ERP technology may improve our understanding of the relationships between preferred sensory modality and information processing. It may be possible, then, to train "verbal" processors better with auditory material and "spatial" processors better with visual material.

Earlier ERP research at NAVPERSRANDCEN has been described in several reports. The first demonstrated that brain wave measures were useful in predicting the success of Navy remedial reading trainees (Lewis, Rimland, & Callaway, 1976); the second described relationships between visually stimulated ERPs and Navy paper-and-pencil aptitudes tests (Lewis, Rimland, & Callaway, 1977); the third and fourth reports showed that visual ERPs could be used to differentiate between pilots and radar intercept officers (Lewis, 1979; Lewis & Rimland, 1979); and the most recent report demonstrated that visual ERPs could be used in predicting the performance of sonar operators (Lewis & Rimland, 1980).

METHOD

Subjects

Fifty right-handed subjects ranging in age from 17 to 20 were tested for this study. The subjects were Caucasian males undergoing Navy enlisted basic training. Audition and vision of the subjects tested normal.

Paper-and-Pencil Measures

Six cognitive style measures and five aptitude and ability indices were obtained from each subject. The cognitive style measures were:

1. Field independence vs. field dependence (FLD). FLD provided a measure of each subject's tendency towards either analytical or global processing. The instrument used to measure FLD was the Hidden Figures Test, Part I (Ekstrom, French, Harman & Dermen, 1976).

2. Conceptualizing style (CON). CON provided a measure of the degree to which each subject differentiated between objects (span of conceptual category). The instrument used was the Clayton-Jackson Object Sorting Test (Clayton & Jackson, 1961).

3. Reflectiveness-impulsiveness (REFL). REFL provided a measure of each subject's tendency to act either deliberately or implusively. The instrument used was the Impulsivity Subscale, from the Personality Research Test, Form E (Jackson, 1974).

4. Tolerance of ambiguity (TOL). TOL provided a measure of each subject's tolerance of ambiguous situations (inclination to accept complex issues). The instrument used was the Tolerance of Ambiguity Scale, from the Self-Other Test, Form C (Rydell & Rosen, 1966).

5. Category width (CATW). CATW provided a measure of each subject's tendency toward either broadness (errors of inclusion) or narrowness (errors of exclusion) in decision making (consistency of cognitive range). The instrument used was the Category Width Scale (Pettigrew, 1958).

6. Cognitive Complexity (COG). COG provided a measure of the extent to which each subject differentiated between environmental factors (multidimensional perception of the environment). The instrument used was the Group Version of Role Construct Repertory Test (Bieri, Atkins, Briar, Leaman, Miller, & Tripodi, 1966).

Further discussion of these stylistic measures may be seen in Federico (1978), Federico and Landis (1979 a & b, 1980).

The five aptitude and ability tests included:

1. General Aptitude (AFQT). The Armed Forces Qualification Test scores provided an index of each subject's general aptitude, ability to comprehend language, solve arithmetic problems, and visualize objects in space. The instruments used were the Word Knowledge Subtest, Arithmetic Reasoning Subtest, and Space Perception Subtest, Armed Services Vocational Aptitude Battery.

2. Reading Comprehension (RGL). RGL provided an index of each subject's ability to understand English words and prose passages. The instrument used was the Gates-MacGinitie Reading Test (Gates & MacGinite, 1965).

3. Verbal Comprehension (VERB). VERB provided an index of each subject's ability to understand the English language. The instrument used was the Vocabulary Test II (Ekstrom et al., 1976).

4. Visualization (SPA). SPA provided an index of each subject's ability to manipulate spatial patterns. The instrument used was the Surface Development Test (Ekstrom et al., 1976).

5. Logical Reasoning (LOG). LOG provided an index of each subject's ability to deduce from premise to conclusion. The instrument used was the Nonsense Syllogisms Test, Part I (Ekstrom et al., 1976).

The AFQT and RGL scores were obtained through military records, while VERB, SPA, and LOG tests were obtained from the Educational Testing Service (ETS) battery and were given to each subject at the same time as the cognitive style tests.

Instrumentation

Data were acquired on a field-portable computer system which included:

1. Central processing unit (CPU, Data General NOVA 2/10, 32k memory).

2. Dual-drive floppy disk unit (Advanced Electronics Design, Inc., Model 2500).

3. Optically isolated and multiplexing EEG unit with band pass set for 0.2-30 Hz.

4. Video display (Panasonic 14-inch Model WV 5400) integrated into the CPU, used to present visual stimuli to subjects and to display the analyzed ERP data.

5. Video hard copy unit (Tektronix Model 4632), used for permanent storage of all video information.

6. Headphones (Sennheiser Model 424X), used for binaural presentation of the auditory stimuli (clicks). Headphone leads were shielded to minimize click artifacts.

7. Sound level meter, used for measuring intensity of clicks used as auditory stimuli (Bruel and Kjaer Impulse Sound Level Meter, Model 2209, One Third Octave Filter Set, Model 1616).

8. Elastic helmet (Lycra).

9. Electrodes (Beckman minatures, 11 mm).

Stimuli

All stimuli were presented aperiodically with the interstimulus intervals ranging from 1.0 to 3.0 seconds, and averaging about 2.0 seconds.

The visual stimulus was a CPU-generated black and white checkerboard pattern presented on the video display for about 2 msec. The checkerboard pattern subtended a binocular visual angle of about 9 degrees, with each check subtending an angle of about 17 minutes. Average background luminance was about 0.4 foot-Lambert (ftL), while the average stimulus luminance was about 5 ftL. The auditory stimulus was a click presented binaurally over the headphones for about 2 msec. Click intensity was about 65 db(A). The bimodal stimulus consisted of the simultaneous presentation of the checkerboard pattern and a click.

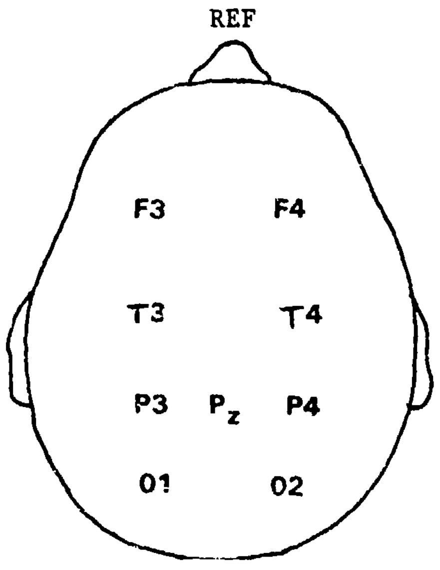
During all ERP recording periods, white noise was presented to the subjects through the headphones and via a speaker in the sound chamber (approximately 50 db(A)).

Procedures

The subjects were prepared for ERP recording after they had received brief instruction, completed a brief background questionnaire, and signed the voluntary consent form.

The helmet, fitted with plastic holders for the electrodes, was placed on the subject's head. The subject's hair was parted and his scalp was cleaned with an alcohol-impregnated cotton swab placed through the holders. Electrode paste was placed on the holders and rubbed onto the scalp. The electrodes were fitted with a 38mm long plastic tube filled with electrolytic solution. A small micro-cell foam sponge held the electrolytic solution in the tube and made contact with the electrode paste on the scalp. The extension tube held the electrode in place and minimized slow voltage drifts caused by changes in scalp temperature. The scalp-to-electrode impedance was 2-3K Ohms.

Visual, auditory, and bimodal ERP data were acquired from eight homologous sites in the frontal, temporal, parietal, and occipital areas (Figure 1). Sites F3 and F4 are over the frontal lobe, an association area. Sites T3 and T4 are over the temporal region, a primary auditory reception area and an area where many visual and auditory nerve fibers interconnect. Sites P3 and P4 are over the left and right parietal lobes, a primary association area. Sites O1 and O2 are over the occipital area--the visual reception area. Ground was in the mid-parietal area and the reference was obtained from the nose using an electrode attached by a standard two-sided wafer. See Jasper (1958) for a more thorough discussion of the electrode sites. The Lycra helmet and all ten electrodes could be attached to the subject in 6 to 8 minutes.



Legend.

F3 = Left frontal	F4 = Right frontal
T3 = Left temporal	T4 = Right temporal
P3 = Left parietal	P4 = Right parietal
O1 = Left occipital	O2 = Right occipital
P_z = Mid-parietal (ground)	REF = Nose (reference)

Figure 1. Electrode sites.

The next step was to show the subject how muscle artifacts could contaminate the ERP data. With all electrodes in place, the subject was instructed to move his jaws, eyebrows, etc., and to observe his real-time EEG activity on the display.

The subject was then seated in a sound chamber in alignment with the display. A hand-held switch allowed the subject, when about to move, sneeze, or scratch, to suspend all stimulus presentation and analysis operations, thereby eliminating muscle artifact. Facilities for additional artifact rejection, prior to storing the data, were available to the console operator.

Figure 2 shows sample ERP data output for the visual (VERP) and auditory (AERP) presentations. These ERP data were retrieved from floppy diskette storage and the required computations were performed. The data were then displayed on the video monitor and a hard copy was obtained. Bimodal ERP data were also computed and displayed in a similar manner.

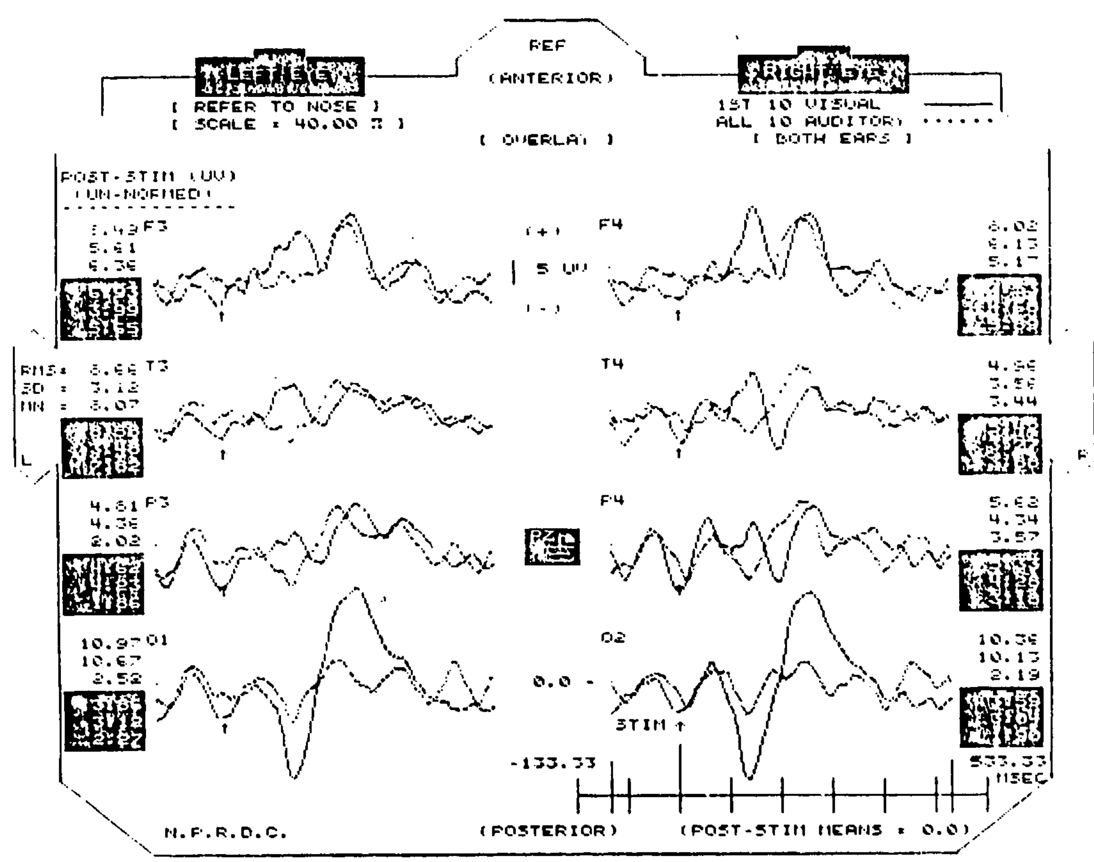


Figure 2. Sample visual and auditory ERP data. Data in the left column were derived from the left hemisphere; and data in the right column, from the right hemisphere. From top to bottom, the records are from the frontal, temporal, parietal, and occipital regions.

The visual and auditory ERP curves are overlaid in Figure 2. All amplitudes are in microvolts. Root mean square (RMS) and standard deviation (SD) amplitude values are presented along with the waveform mean (MN) values for the half-second (533 milliseconds) post-stimulus period. SD amplitude values are normalized RMS values, that is, the waveform mean has been set to zero. Only the SD amplitude values were used for the analyses. Pre-stimulus waveforms (133 msec), calibration, polarity, DC offset, time base, and other items of information were also displayed. The waveforms in the left column were derived from the left hemisphere; waveforms on the right were from the right hemisphere. The waveforms from top to bottom of the display were from the front to the back of the head at the frontal, temporal, parietal, and occipital sites.

Some subjects received the written tests before making the ERP recordings, others after. The order in which the written tests were given, and the order in which the ERPs were recorded, were also varied.

RESULTS

Cluster Analysis of Paper-and-Pencil Test Results

The results of the individual paper-and-pencil tests did not reveal any significant differences in type until they were entered into a cluster analysis (NORMIX, Wolfe, 1970). The cluster analysis provided two sets of individuals that will be called the spatial and the verbal groups. The two groupings were determined from discriminant function coefficients primarily related to the RGL and VERB scores.

Table 1 presents the paper-and-pencil test data for the two types. The spatial group was high in SPA, FLD, REFL, TOL, COG, and AFQT, while the verbal group was high in VERB, CON, CATW, RGL, and LOG. The division of the subjects into spatial and verbal groups thus seemed appropriate for a study of ERPs and cognitive style. An interpretation of the test scores is given in Table 2.

Standard Deviation Microvolts (SD μV)

The amplitude values used in this report are calibrated standard deviation microvolts (SDμV, Callaway, 1975). Since not all subjects show well defined ERP components, the SDμV measure has been found to be most effective for assessing individual differences. This measure represents the root-mean-square (RMS) values, with the means removed, of the voltages recorded during the entire 533 millisecond post-stimulus period. It has the additional advantage of allowing researchers to describe the amplitude of a complex waveform with a single value.

ERP Amplitudes

ERP data for all eight sites in all three stimulus modes are presented in Table 3. The visual ERPs were generally greater for the spatial group than for the verbal group. The greatest amplitude differences occurred at the right hemisphere frontal and temporal sites (F4 and T4).

Auditory ERPs were larger for the spatial group than for the verbal group at right hemisphere sites T4, P4, and O2. They were larger for the verbal group at right hemisphere sites F3, P3, and O1.

Table 1

Paper-and-Pencil Descriptive Data for Spatial and Verbal Groups

Measure	Type 1 (Spatial) $\bar{X}$	Type 1 (Spatial) SD	Type 2 (Verbal) $\bar{X}$	Type 2 (Verbal) SD	Discriminant Function Coefficient
Cognitive Styles:					
FLD	6.94	2.49	2.97	2.78	-.40
CON	11.56	4.02	11.78	4.33	.11
REFL	6.39	4.55	4.91	3.34	-.12
TOL	6.67	2.28	5.34	2.13	-.29
CATW	27.33	11.50	31.50	10.82	.02
COG	83.61	27.03	68.06	16.53	-.04
Aptitude and Abilities:					
AFQT	64.72	16.36	62.81	20.08	-.03
RGL	9.46	2.18	11.23	1.52	.44
VERB	5.94	2.51	7.19	2.43	.46
SPA	34.94	15.44	24.63	16.55	-.03
LOG	-.89	3.51	1.25	4.14	.09

Note. N was 18 for Type 1, 32 for Type 2.

Table 2

Interpretation of Paper-and-Pencil Test Scores

Measure	Spatial Group Tendencies	Verbal Group Tendencies
Cognitive Styles:		
FLD	Analytical, impersonal orientation	Global, personal orientation
CON	Less differentiation of categorized objects	More differentiation of categorized objects
REFL	More impulsive	More reflective
TOL	More tolerant of ambiguity	Less tolerant of ambiguity
CATW	Narrower categories (errors of exclusion)	Broader categories (errors of inclusions)
COG	Less cognitively complex (less differentiating)	More cognitively complex
Aptitude and Abilities:		
AFQT	Higher general aptitude	Lower general aptitude
RGL	Lower reading ability	Higher reading ability
VERB	Lower verbal ability	Higher verbal ability
SPA	Higher spatial ability	Lower spatial ability
LOG	Lower logical reasoning ability	Higher logical reasoning ability

Table 3

ERP Amplitude Data (SD µV) for Spatial and Verbal Groups

Group/Hemisphere/ Electrode Site	Visual ERPs		Auditory ERPs		Bimodal ERPs	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
<u>Spatial Group</u>:						
Left Hemisphere						
Frontal	2.77	1.14	2.55	.84	5.50	2.32
Temporal	2.26	.97	2.45	.73	3.45	1.91
Parietal	2.62	1.27	2.94	1.00	4.24	1.83
Occipital	3.70	1.22	2.78	.75	5.21	1.53
Right Hemisphere						
Frontal	3.07	1.58	2.58	.84	5.03	2.35
Temporal	2.86	1.09	2.52	.87	3.96	1.86
Parietal	3.12	1.42	3.00	1.19	4.37	1.88
Occipital	3.54	1.17	2.85	.71	5.13	1.78
<u>Verbal Group</u>:						
Left Hemisphere						
Frontal	2.76	1.20	2.68	1.15	4.09	1.82
Temporal	2.22	.78	2.44	.87	2.86	1.04
Parietal	2.93	1.23	2.99	1.05	3.93	1.47
Occipital	3.96	1.61	3.12	.98	4.64	1.54
Right Hemisphere						
Frontal	2.67	1.13	2.73	1.11	3.87	1.71
Temporal	2.45	.85	2.34	.65	3.13	1.10
Parietal	3.04	1.14	2.71	.95	3.91	1.35
Occipital	3.72	1.17	2.70	.88	4.70	1.49

<u>Note</u>. N was 18 for the spatial group, 32 for the verbal group.

Bimodal ERPs were considerably larger for the spatial group at all eight electrode sites. Greater differences occurred in the front brain areas (F and T) than in the back areas (P and O).

<u>Sensory Interaction</u>

One approach to assessing the effects of sensory interaction on information processing would be to determine relationships between single stimuli, visual (V) or auditory (A), and the bimodal (B) stimuli. For these purposes we have used the expression [B - (V + A)] (Lewis & Froning, in press). If the value of this expression was positive, the bimodal stimulation was said to be excitatory or facilitory in nature. If the expression was negative, then the bimodal stimulation was said to be inhibitory.

Table 4 presents sensory interaction data derived by means of the expression [B - (V + A)]. All values were negative, suggesting that inhibitory activity occurred when auditory and visual stimuli were presented at the same time. The verbal group showed much greater inhibition than did the spatial group and the difference between the two groups was greater in the left hemisphere. All standard deviation values were considerably greater for the spatial group than for the verbal group.

Table 4

Sensory Interaction Descriptive Data

Hemisphere/ Electrode Site	Spatial (N = 18)		Verbal (N = 32)	
	$\overline{X}$	SD	$\overline{X}$	SD
Left Hemisphere:				
Frontal	-.28	2.57	-1.35	1.54
Temporal	-1.25	1.97	-1.80	1.06
Parietal	-1.32	1.85	-1.99	1.31
Occipital	-1.27	1.74	-2.43	1.57
Right Hemisphere:				
Frontal	-.61	2.69	-1.54	1.46
Temporal	-1.42	1.66	-1.66	.97
Parietal	-1.76	1.90	-1.83	1.08
Occipital	-1.26	1.90	-1.72	1.23

Average ERP and Sensory Interaction Values

The average ERP and sensory interaction values for all four sites on both hemispheres were derived from Tables 3 and 4 and are presented in Table 5. In general, right-hemisphere ERPs were greater for the spatial group and left-hemisphere ERPs were greater for the verbal group.

For the spatial group, ERPs from the right hemisphere were greater than those from the left in all three stimulus modes. Sensory interaction was greater in the right hemisphere than in the left.

Data for the verbal group were less distinct. Visual ERPs were equal for both hemispheres; auditory ERPs from the left hemisphere were larger than those from the right; bimodal ERPs from the right were larger than those from the left. Greater sensory interaction occurred in the left hemisphere than in the right.

Table 5

ERP Values Averaged Over All Four Sites for Both Hemispheres

Measure	Spatial Group (N = 18)				Verbal Group (N = 32)			
	LH		RH		LH		RH	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Visual ERP	2.84	.61	3.15	.28	2.97	.73	2.97	.56
Auditory ERP	2.68	.22	2.74	.23	2.81	.31	2.62	.19
Bimodal ERP	4.49	.81	4.62	.56	3.88	.74	3.90	.64
$\bar{X}$	3.34	--	3.50	--	3.22	--	3.16	--
[(B - (V + A)]	-1.03	.50	-1.26	.48	-1.89	.45	-1.69	.12

Note. LH = left hemisphere; RH = right hemisphere.

Discriminant Analysis

Separate stepwise discriminant analyses (BMDP7M, Brown, 1977) were performed on the basic ERP data, and on the sensory interaction derivations, to determine the optimal variates for the two-group separation. No significant group difference was found for visual, auditory, or bimodal ERP data but the sensory interaction data were highly significant on validation.

The three sensory interaction variates that provided maximum group discrimination were the left occipital (O1), right parietal (P4), and left frontal (F3). At step three, the discriminant function not only provided significant group separation, it also validated the classification of subjects (see Table 6).

Table 6

Discriminant Analysis Summary of Sensory Interaction Variates for Both Groups

Step Number	Discriminant Function: Variate (Electrode Site)	F	dF	Probability	Validated Classification: Group Spatial (S) / Verbal (V)	χ^2	Probability
1	O1	5.87	1,48	.05	S: 16 6 / V: 11 21	3.62	NS
2	P4	3.47	2,47	.05	S: 14 4 / V: 9 23	9.52	.005
3	F3	5.90	3,46	.01	S: 13 5 / V: 8 24	8.70	.005

Correlation Analysis: Spatial Group

Since the discriminant analyses results were highly significant for the sensory interaction data, but not for the visual, auditory, or bimodal, interest was created in exploring relationships between sensory interaction and the paper-and-pencil test data. The resulting correlation matrix for the spatial group appears in Table 7.

Data for the spatial group suggest highly significant correlations within the sensory interaction variates, but relationships between the sensory interaction variates and the paper-and-pencil tests were generally low. COG was positively related to sensory interaction at the F3, F4, and T4 sites and SPA was significantly related to the T3 site.

With few exceptions, the within paper-and-pencil test score relationships were not significant. Most noticeable were the high relationships between SPA and AFQT and between SPA and RGL. VERB was related to AFQT, FLD, and CON. LOG was significantly related to VERB for the spatial group, but not for the verbal group. Of special interest was the very low relationship between VERB and RGL.

Correlation Analysis: Verbal Group

Relationships within and between the sensory interaction variates and written tests for the verbal group appear in Table 8. The correlations within the sensory interaction variates were significant, but were less than for the spatial group. Relationships between sensory interactions and test scores were generally higher than for the spatial group. REFL related significantly and positively with sensory interaction recorded at O1 and O2, whereas these relationships were negative and not significant for the spatial group.

Relationships within the written test scores were generally low, but were higher than for the spatial group. The verbal group showed a highly significant relationship between VERB and RGL, a finding of special interest as this relationship was not significant for the spatial group. In addition, LOG related to the AFQT score for the verbal group, which it did not for the spatial group. LOG did not show a significant relationship with CATW for the verbal group, though, as it did for the spatial group.

Lateral ERP Asymmetry: Spatial Group

One way to assess the relative functioning of the hemispheres is to examine ERP asymmetry at homologous electrode sites. Asymmetry is defined here as the right minus left amplitude (R - L) for a given brain area. Asymmetry data for both groups appear in Table 9.

The spatial group's mean visual ERP asymmetry was positive (i.e., the visual ERPs were greater over the right hemisphere than over the left) and greater than that of the verbal group. Bimodal asymmetry was greatest in the temporal area. This value was nearly twice that of the verbal group.

Lateral ERP Asymmetry: Verbal Group

The verbal group showed more auditory ERP asymmetry than did the spatial group (Table 9). The verbal group also showed increasing negative lateral asymmetry going from the front to the back of the head. The mean for the verbal group (-.19) was negative (i.e., the ERP amplitude was greater over the left hemisphere than the right).

Table 7

Correlation Matrix for the Spatial Group (N = 18)

	Left Hemisphere Sensory Interaction				Right Hemisphere Sensory Interaction				Paper-and-Pencil Measures										
Measures	F3 (1)	T3 (2)	P3 (3)	O1 (4)	F4 (5)	T4 (6)	P4 (7)	O2 (8)	AFQT (9)	RGL (10)	FLD (11)	CON (12)	REFL (13)	TOL (14)	CATW (15)	COG (16)	VERB (17)	SPA (18)	LOG (19)
1. SI F3	—																		
2. SI T3	.80**	—																	
3. SI P3	.67**	.84**	—																
4. SI O1	.41	.55*	.78**	—															
5. SI F4	.97**	.75**	.72**	.54*	—														
6. SI T4	.89**	.82**	.78**	.59**	.92**	—													
7. SI P4	.69**	.72**	.91**	.81**	.77**	.85**	—												
8. SI O2	.58**	.51*	.68**	.87**	.68**	.63**	.78**	—											
9. AFQT	.29	.36	.21	.08	.18	.20	.07	.12	—										
10. RGL	.33	.37	.30	.26	.33	.25	.28	.32	.40	—									
11. FLD	.23	.14	.26	.10	.20	.23	.23	.23	.26	-.07	—								
12. CON	.52*	.45	.36	.02	.43	.42	.33	.26	.47*	.32	.53*	—							
13. REFL	.12	.08	-.02	-.10	-.01	-.07	-.15	-.01	.52*	-.09	.16	.01	--						
14. TOL	-.38	-.19	.10	.08	-.33	-.33	-.02	.06	.31	.11	.23	.13	.29	—					
15. CATW	.33	.18	-.11	-.25	.18	.11	-.16	.00	.44	-.10	.24	.39	.58**	-.03	—				
16. COG	.46*	.29	.22	.08	.48*	.46*	.39	.32	-.31	.27	-.09	.29	-.38	-.27	-.10	—			
17. VERB	.20	.21	.26	.10	.13	.20	.20	.09	.59**	.09	.77**	.48*	.38	.36	.17	-.26	—		
18. SPA	.41	.50*	.44	.31	.38	.36	.40	.37	.60**	.84**	.15	.43	.05	.16	.02	.14	.35	—	
19. LOG	.40	.20	.05	-.11	.35	.14	-.10	.09	.44	-.02	.22	.19	.55*	.10	.66**	-.12	.21	.14	—

*p < .05.
**p < .01.

Table 8

Correlation Matrix for the Verbal Group (N = 32)

Measures	Left Hemisphere Sensory Interaction				Right Hemisphere Sensory Interaction				Paper-and-Pencil Measures										
	F3 (1)	T3 (2)	P3 (3)	O1 (4)	F4 (5)	T4 (6)	P4 (7)	O2 (8)	AFQT (9)	RGL (10)	FLD (11)	CON (12)	REFL (13)	TOL (14)	CATW (15)	COG (16)	VERB (17)	SPA (18)	LOG (19)
1. SI F3	—																		
2. SI T3	.62**	—																	
3. SI P3	.55**	.67**	—																
4. SI O1	.18	.32	.55**	—															
5. SI F4	.79**	.64**	.56**	.10	—														
6. SI T4	.57**	.48**	.54**	.14	.55**	—													
7. SI P4	.41*	.41*	.74**	.57**	.41*	.50**	—												
8. SI O2	-.01	.19	.38*	.85**	-.03	.02	.55**	—											
9. AFQT	.41*	.05	.12	.16	.18	.33	.14	.07	—										
10. RGL	.23	.09	.18	.35*	.07	.43*	.35*	.35*	.58**	—									
11. FLD	-.29	-.36*	-.24	.13	-.32	-.05	-.21	.01	.41*	.28	—								
12. CON	.08	-.05	.16	.29	.13	.12	.10	.13	.32	.26	.27	—							
13. REFL	.15	.22	.29	.47**	.16	.24	.56**	.47**	-.07	.10	.03	.14	—						
14. TOL	.08	.05	.09	.08	-.07	.08	.12	.01	.36*	.37*	-.07	-.12	-.20	—					
15. CATW	.13	-.03	.18	.12	.09	.08	.06	-.11	.07	-.07	-.06	.07	-.27	.48**	—				
16. COG	-.17	-.04	.09	-.04	.06	.02	.19	.19	-.19	.14	-.22	.22	.06	-.20	-.13	—			
17. VERB	.03	-.34	-.16	.20	-.20	.11	.06	.20	.69**	.55**	.59**	.21	.19	.27	.03	.02	—		
18. SPA	.40*	.08	.24	.30	.26	.39*	.22	.13	.81**	.43*	.34	.32	.06	.28	.28	-.19	.56**	—	
19. LOG	.31	.16	.18	-.04	.22	.30	.08	-.14	.50**	.23	.17	-.36*	-.06	.37*	.11	-.30	.47**	.39*	—

*p < .05.
**p < .01.

Table 9

ERP Amplitude Asymmetry (R-L)

Electrodes Sites	Visual ERP Asymmetry		Auditory ERP Asymmetry		Bimodal ERP Asymmetry	
	Spatial	Verbal	Spatial	Verbal	Spatial	Verbal
Frontal	.30	-.09	.03	.05	-.02	-.22
Temporal	.60	.23	.07	-.10	.51	.27
Parietal	.50	.11	.06	-.28	.13	-.02
Occipital	-.16	-.24	.07	-.42	.08	.06

Note. These data were derived from Table 3. Asymmetry is in SD µV.

Front and Back Lateral Asymmetry: Spatial Group

Earlier research has shown interesting and promising lateral asymmetry relationships between the front and back areas of the brain (Lewis, 1980). The front and back relationships plotted in Figure 3 were derived from Table 9. Front values were obtained by averaging the frontal and temporal asymmetries, while back values were derived from the parietal and occipital asymmetries.

This spatial group's average front asymmetry was largest for visual ERPs and smallest for auditory. Bimodal ERPs approximated the average of the combined visual and auditory. In all modalities, values were positive. The back area asymmetry showed an approximately linear decrease from visual to auditory to bimodal ERPs.

Front and Back Lateral Asymmetry: Verbal Group

The verbal group's average front visual ERP asymmetry was positive, but considerably smaller than that of the spatial group. Front auditory ERP asymmetry was slightly negative. Front bimodal asymmetry was slightly positive, and less than for the spatial group. The back averages were slightly negative for visual ERPs, considerably negative for auditory, and slightly positive for bimodal.

Average Lateral Asymmetry

Table 10 shows the asymmetry data averaged over the entire head. The spatial group displayed a large amount of positive (R > L) asymmetry from visual stimuli. The verbal group showed a large amount of negative (L > R) asymmetry from auditory stimuli. Bimodal stimulation produced asymmetry in both groups, with the spatial group showing greater asymmetry than the verbal group.

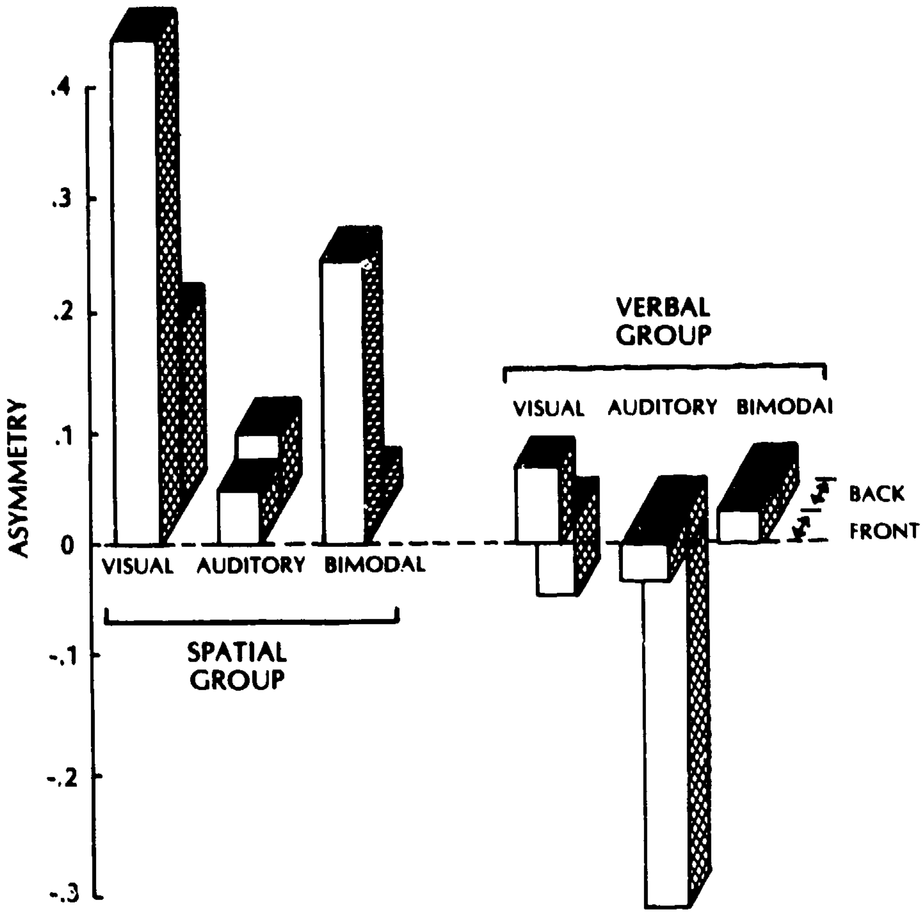


Figure 3. Front and back lateral asymmetries.

Table 10

Average Asymmetry Over Entire Head

Stimuli	Spatial Group	Verbal Group
Visual	.31	.00
Auditory	.06	-.19
Bimodal	.14	.02

Note. This table derived from Table 9. Asymmetry values are in SD μV.

Sensory Interaction Asymmetry

Sensory interaction asymmetry values were also computed (Table 11). The spatial group showed primarily negative asymmetries, which suggests greater inhibition in the right hemisphere than the left. The verbal group showed primarily positive asymmetries, greatest in the occipital region.

Table 11

Sensory Interaction Asymmetry

Site	Spatial Group	Verbal Group
Frontal	-.33	-.19
Temporal	-.17	.14
Parietal	-.44	.16
Occipital	.01	.71
Mean	-.23	.21

Note. This table derived from Table 4. Asymmetry values are in SD μV.

Within the spatial group, visual stimuli produced the greatest ERP asymmetry, with right hemisphere amplitudes greater than left. Within the verbal group, auditory stimuli produced the greatest ERP asymmetry, with left hemisphere amplitudes greater than right. These findings were expected from the lateral brain asymmetry model.

Other research has suggested that, as ability increases, greater asymmetry occurs (Lewis & Froning, in press). Therefore, perhaps, the greater the asymmetry, the more sensitive the student's progress may be to the selection of the appropriate training modality.

DISCUSSION AND CONCLUSIONS

No individual paper-and-pencil measures or ERP variates were able to clearly distinguish the spatial group from the verbal group, but interesting differences were found in the areas of sensory interaction and lateral asymmetry.

Sensory Interaction

It was hypothesized that the sensory interaction created by the simultaneous presentation of multiple stimuli would result in either the excitation or inhibition of brain activity. Even though both groups showed inhibition when visual and auditory stimuli were presented together, the verbal group showed greater hemispheric differences in the amount of inhibition. The spatial group showed greater inhibition in the right hemisphere than in the left. Perhaps greater activation was occurring in the right hemisphere, since it is thought to be more involved with spatial processing. The verbal group showed greater inhibition in the left hemisphere than in the right. Again, perhaps greater

activation was occurring in the left hemisphere, since it is thought to be the one most involved in verbal processing.

Cluster Analyses

Cluster analyses, similar to those performed on the paper-and-pencil measures, were also performed using ERP variates. No significant grouping or typing occurred with our subjects.

Discriminant Analyses

Individual sensory interaction variates, unlike individual test scores, provided significant type differences when subjected to discriminant analyses. ERP measures thus showed greater sensitivity in assessing laterality and "processing" functions than did the written tests. It is suggested that ERP measures may be better able to distinguish between "verbal" and "spatial" processing individuals than existing paper-and-pencil tests or other behavioral procedures.

Follow-on Exploratory Development

The researchers assumed that the six written cognitive style tests really did measure predominant modes of information processing. With further development, it may be possible to assess brain information processing better with direct brain recordings than with paper-and-pencil measures.

The ERP procedures and results discussed in this report are being extended by recording brain activity during the performance of Navy-relevant tasks. The tasks include learning radar system definitions and concepts (hypothesized as primarily left hemisphere processing), and learning/identifying radar jamming procedures (hypothesized as primarily right hemisphere processing). Preliminary results seem promising. Relationships between ERP and learning and performance measures will be assessed to determine their possible use in increasing the efficiency of adaptive training and in predicting performance.

FUTURE DIRECTION

Research is now underway to assess the usefulness of ERPs recorded while subjects are learning and performing electronic warfare tasks. Additional research will be conducted to determine whether training can be enhanced by emphasizing visual media, when training "spatial processing" students, and by emphasizing auditory media when training "verbal processing" students.

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